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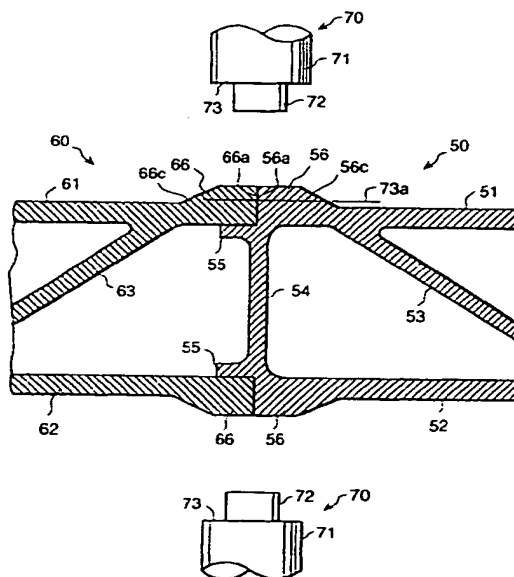
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(54) Friction stir welding method, frame members used therein, and product formed thereby

(57) Disclosed is a friction stir welding technique which avoids occurrence of a dent, in a joining region, extending to a level beneath the joined surfaces. At end portions of the frame members (50, 60) to be joined, at the joining region, thickened parts which project toward the rotary body joining tool (70) are provided. Two adjoining thickened parts, of adjacent members to be joined, can form a trapezoid shape. The rotary body joining tool has a small-diameter tip portion and a larger diameter portion. The rotary body joining tool is inserted in the thickened parts. In a state where the rotary body joining tool has been inserted small-diameter tip end first, to a level where the larger diameter portion of the rotary body joining tool overlaps the thickened part but does not extend below the upper surface of the non-thickened surfaces of the members joined, the rotary body is rotated and moved along the joining region. Even when a gap exists between two thickened parts, a desirable joining can be carried out. After the joining, the remaining parts of the thickened parts can be machined so as to form a smooth surface.

FIG. 1



## Description

The present invention relates to a friction stir welding method suitable for use in a joining of members of various materials, including, for example, an aluminum alloy member, etc.

A friction stir welding method is a method in which by rotating a round-shaped rod (a rotary body) inserted in a joining region between two members (e.g., but not limiting, two metal bodies, such as two Al bodies), and further by moving the rotary body along a joining line, the two bodies at the joining region are heated, and material thereof softened and plastically fluidized and thus the two bodies are solid-phase joined, e.g., are welded together at the joining region.

Conventionally, the rotary body comprises a small diameter portion which is inserted in the joining region and a large diameter portion which is positioned outside the joining region. The small diameter portion and the large diameter portion are positioned on the same axis. A side of the large diameter portion is rotated, whereby both the large and small diameter portions are rotated. A boundary portion between the small diameter portion and the large diameter portion can be inserted a little into the joining region. A joining according to the friction stir welding method can be applied to an abutting portion and an overlapping portion.

The above-stated prior technique is disclosed, for example, in Japanese patent announcement laid-open publication No. Hei 7-505090 (EP 0615480 B1); Dawes, "An Introduction to Friction Stir Welding and Its Development", in Welding & Metal Fabrication (January 1995), pages 13, 14 and 16; and by U.S. Patent application Serial No. 08/820,231, filed March 18, 1997, the contents of which are incorporated herein by reference in their entirety.

This prior technique is also described in the article by T. Shinoda and Y. Kondoh, "324 Butt Welding of Plate Using Friction Stir Welding; Method Study of Friction Stir Welding", Welding Associate Japan Lecture Meeting Outline, No. 56 (April 1995), pages 208 and 209. This article discloses a rotary body (rotary tool) made of stainless steel, members to be welded (joined) made of pure aluminum (A1100), and the members to be welded having a plate thickness of 6 mm. The rotary body has a large diameter portion with a diameter of 20 mm, and a small diameter portion (cylindrical) with a diameter of 6 mm and a length (axially) of 5 mm. In operation, the rotary body rotates at 1000-2500 rpm, and moves along the two members to be welded at a speed of 1.0-8.0 mm/s.

In the article described in the foregoing paragraph, the members to be joined are made of aluminum. Alloys of aluminum are also suitable for welding by friction stir welding; other metals studied for welding by friction stir welding include copper, titanium and stainless steel. EP 0615480 B1, referred to previously herein, discloses friction stir welding of plastic (e.g., thermoplastic) mate-

rials. All of these materials can be welded by the process of the present invention.

According to various experiments of the friction stir welding method, a part of an upper face of a joining region of two members is machined as chips, by a rotation of the large diameter portion of the rotary body, and a dent is caused in the upper face of the joining region. At both sides of the dent, a thickened part is caused according to plastic deformation of the members.

It is easy to delete the thickened part; however, correcting for the dent needs a putty working, etc., and as a result a high manufacturing cost is caused.

Further, in a case where before the joining working a gap exists between end faces of the abutting faces of the two members, a default such as a dent, etc., is generated at the joining region. As a result, a lowering in strength is caused, and particularly in a large-scale construction it invites a problem. The larger the members, the more a management in the above-stated gap becomes difficult (i.e., the more the gap occurs); accordingly, the dent becomes large, and, moreover, a default is generated easily.

In a case where the joining region is covered by another member, for example, the existence of the dent is not as much a problem, and there is no problem except for the strength problem (which, of course, can be a serious problem itself). However, in a side face, etc., of a car body of cars (e.g., railroad cars), it is necessary to remove the dent from a viewpoint of an outward appearance. Further, even in a case where the dent is not visible, the dent becomes a problem from an aspect of the performance (e.g., strength of the weld).

Preferably, an object of the present invention is to prevent generation of a dent in a joining region when joining two members (e.g., but not limited to, two metal members, such as of aluminum alloy) by a friction stir welding method.

Preferably, another object of the present invention is to provide members, to be joined by friction stir welding, which avoid a dent in the joining region between the joined members.

Preferably, still another object of the present invention is to provide a friction stir welding method, and product manufactured thereby, whereby a dent can be avoided in the joining region between joined members, where the members joined are abutting each other before being joined or even where there is a small gap between the members before they are joined (but the members are adjacent each other).

Preferably, the above-stated objects can be attained by a provision where at least one of the members to be joined has a thickened part, in cross section, at the joining region thereof with another member, the thickened part protruding toward the rotary body used to perform the friction stir welding. The rotary body has large and small diameter portions, e.g., made of a material or materials harder than the material of the members to be welded, the small diameter portion first being inserted

in the joining region of the members to be joined, during the joining. The members to be joined are positioned adjacent each other, with the thickened part of one member being positioned adjacent the other member to be joined thereto by welding. Where both members have thickened parts, the thickened parts can be positioned adjacent each other in the joining (joint-forming) region, or only one thickened part need be positioned in the joint-forming region. The rotary body is then caused to enter between the two members, in the joining region, with the small diameter portion of the rotary body being inserted into the joint-forming region of the two members and the large diameter portion of the rotary body extending into the thickened part (but not below the thickened part). The rotary body is then moved along the members to be welded, in the joining region, with the rotary body inserted as described in the previous sentence to perform the friction stir welding. Due to provision of the thickened part, at the joint-forming region, a dent (depressed region) at the weld region, in the joined members, can be avoided. By positioning the rotary body such that the large-diameter portion thereof is inserted into the thickened part (overlaps with the thickened part), an excellent weld is achieved, while avoiding a dent in the welded joint. Advantageously, the large-diameter portion of the rotary body does not extend below the protruding portion of the thickened part, while moving the rotary body to perform the friction stir welding.

The thickened part of the member can be an integral part of the member, and, e.g., extends to the edge (of the member) which is to be positioned adjacent another member to which the member is to be welded.

Preferably, the protruding portion has a side, furthest from the weld location, which, in cross section, is sloped (e.g., makes an acute angle of less than 90° with the plane of the surface of the member (other than the protruding portion); see  $\theta$  in Fig. 4). Desirably, this side furthest from the weld location makes an angle of 15°-60°, preferably 30°, with the plane of the surface of the member.

Figure 1 is a longitudinal cross-sectional view showing a part of one embodiment according to the present invention.

Figure 2 is a longitudinal cross-sectional view showing a state after a friction stir welding of the structure of Fig. 1.

Figure 3 is a longitudinal cross-sectional view showing a state in which after a friction stir welding of the structure of Fig. 1 has been carried out, a finishing process is carried out on one side.

Figure 4 is a view for explaining dimensions.

Figure 5 is a perspective view showing a car body of a railway car.

Figure 6 is a longitudinal cross-sectional view showing a part of another embodiment according to the present invention.

Figure 7 is a lateral cross-sectional view showing a joining region of another embodiment according to the

present invention.

Figure 8A is a longitudinal cross-sectional view showing a joining apparatus of one embodiment according to the present invention.

Figure 8B is a longitudinal cross-sectional view of part of another embodiment according to the present invention.

Figure 8C is a left-side view of Figure 8B.

Figure 8D is a longitudinal cross-sectional view of a part of a further embodiment according to the present invention.

Figure 9 is a longitudinal cross-sectional view showing a joining region of a further embodiment according to the present invention.

Figure 10 is a longitudinal cross-sectional view showing a welded structure after a friction stir welding of the structure of Fig. 9.

Figure 11 is a longitudinal cross-sectional view showing the resulting structure after a thicker part of the structure in Fig. 10 is finished smoothly.

Figure 12 is a longitudinal cross-sectional view of a joining region of another embodiment according to the present invention.

Figure 13 is a longitudinal cross-sectional view showing the resulting structure after a friction stir welding of the structure shown in Fig. 12.

Figure 14 is a longitudinal cross-sectional view showing the resulting structure after a thicker part of the structure shown in Fig. 13 is finished smoothly.

Figure 15 is a longitudinal cross-sectional view of a joining region of another embodiment according to the present invention.

Figure 16 is a longitudinal cross-sectional view showing the resulting structure after a friction stir welding of the structure shown in Fig. 15.

Figure 17 is a front view of a side structure body of a railway vehicle.

Figure 18 is a cross-sectional view taken along the line XVIII-XVIII of Figure 17.

Figure 19 is a right-side view of Figure 18.

Figure 20 is a longitudinal cross-sectional view of a part of a further embodiment according to the present invention.

## DETAILED DESCRIPTION OF THE INVENTION

One embodiment of the present invention, which is an application of the present invention for a car body of railway cars, will be explained referring to Figs. 1-5.

In Fig. 5, a car body of a railway car is comprised of a side constructive body 41, a roof constructive body 42, a floor constructive body 43, and a constructive body 44 of an end portion at a longitudinal direction. The side constructive body 41 is constituted by arranging plural hollow extruded frame members (50, 60) and by joining contacting portions thereof. The joining is carried out as shown in Fig. 1.

Each of the roof constructive body 42 and the floor

constructive body 43 is constituted similarly. Connections between the side constructive body 42 and the roof constructive body 41 and the floor constructive body 43 are carried out using an MIG (metal electrode inert gas) welding, etc.

Fig. 1 shows a joint portion of a hollow frame member which constitutes the side constructive body 41. The hollow frame members 50 and 60 are extruded frame members made from an aluminum alloy, for example. The hollow frame members 50 and 60 each comprise two plates 51, 52 and 61, 62, and diagonal plates (ribs) 53 and 63 which connect the plates. The plural diagonal plates 53 and 63 are arranged with a truss shape. The inclination directions of the plates 53 and 63 are alternately.

An end portion of one hollow frame member 50 is entered into an end portion of another hollow frame member 60. A vertical plate 54 for joining the plate 51 and the plate 52 is provided at a vicinity of the end portion of the hollow frame member 50. A reference numeral 54 is an extruded member for supporting the end portion of the hollow frame member 50.

On an extension line of a center of the thickness direction (in Fig. 1, a right and left direction) of the plate 54, the end portions of the members to be joined have thickened parts (protruding portions) of the two hollow frame members 50 and 60. Namely, an end portion (a center of a welding region W) of each of the hollow frame members 50 and 60, at which the joining is performed, is thickened so as to form the protruding portions.

The plates 51, 52 and 61, 62 are positioned nearly to the welding region W (see Fig. 2, for example) and are extruded and formed thick to form the thickened parts at a side of a front face (an outside in the thickness direction of the hollow frame member, or a side facing the tool for carrying out the joining working (welding), namely, a side facing the rotary body 70 which is a tool for friction stir welding.

The thickened parts 56 and 66 are formed respectively at the end portions of the plates 51, 52 and 61, 62. The front faces (the outer faces) of the thickened parts 56 and 66 are connected smoothly and inclined toward the front faces (the outer faces) of the plates (the non-thickened portions, which may be planar) 51, 52 and 61, 62. When two thickened parts 56 and 66 are aligned, then they can form a trapezoid shape illustrated in Fig. 1, although the present invention is not limited to the aligned parts 56 and 66 forming a trapezoid shape.

The rotary bodies 70 and 70, which are the joining tools for friction stir welding, are arranged respectively at an upper portion and at a lower portion of the joining regions of the hollow frame member. Each rotary body 70 has a small diameter round-shape rod 72 (a smaller diameter portion) at a tip end of a large diameter round-shape rod (a larger diameter portion) 71 which acts as a base portion. The large diameter portion 71 and the small diameter portion 72 are disposed on the same axis.

The lower side rotary body 70 is positioned downwardly substantially vertically below the upper side rotary body 70. The rotary bodies 70 and 70 can be separated along the joining line; however, to prevent bending of the hollow frame members 50 and 60, it is desirable to not separate the upper and lower rotary bodies a large distance in the direction along the joining line. The material of the rotary body 70 is harder than the materials of the hollow frame members 50 and 60.

By rotating the two rotary bodies 70 and 70, the small diameter portion 72 is inserted into the joining region of the hollow frame members 50 and 60. After that, the two rotary bodies 70 and 70 are moved in the horizontal direction along the longitudinal direction of the joining region of the hollow frame members 50 and 60. The two rotary bodies 70 and 70 are moved at the same time.

During the friction stir welding, at a side of the upper side rotary body 70, a boundary portion 73 (a substantially flat shape portion), between the large diameter portion 71 and the small diameter portion 72 of the rotary body 70, is positioned spaced upward a little, at an upper portion 73a (at a side of a face of an apex of the thickened parts 56 and 66 and in an inner portion of the thickened parts 56 and 66), from an extension of an upper face of the general portion (the non-projecting portion) of the plates 51 and 61. That is, while the large diameter portion 71 of the upper side rotary body 70 extends below the upper face of the thickened part (e.g., is inserted into the thickened part), it does not extend below the level of the non-projecting portion of the plates 51 and 61.

At a side of the lower side rotary body 70, the boundary portion 73 between the large diameter portion 71 and the small diameter portion 72 is positioned a little below an extension of a lower face of the general portion (the non-projecting portion) of the plates 52 and 62 (between the face side of the apex of the thickened parts 56 and 66 and in an inner portion of the thickened parts 56 and 66).

Namely, the boundary portion 73 between the large diameter portion 71 and the small diameter portion 72 is positioned at an outer side of the extension line of the face of the outer side of the non-projecting portion of the plates 51 and 52, and further is positioned in the inner portion of the thickened parts 56 and 66. In Fig. 1, the line 73a indicates a position of the boundary portion 73. In other words, the large diameter portion is inserted to a position (with respect to the upper rotary body) below the apex of the thickened part but not below the extension line of the non-projecting portion of the plates 51 and 52; the large diameter portion of the lower rotary body is correspondingly inserted.

In a case of performing the welding, the frame members 50 and 60 are mounted on a bed stand and are fixed thereto. No bed stand exists at a surrounding portion of the thickened part of the lower face. A rotating center of the rotary body 70 is a center of the joining

region; namely, such center is a center of the thickness of the plate 54.

In Fig. 4, a relationship about the dimensions of the respective portions will be explained. A width W1 of an apex of the two thickened portions 56 and 66 (two welding portions 56 and 66), in a case where the two thickened portions 56 and 66 (two welding portions 56 and 66) are abutted, is larger than a diameter d of the small diameter portion 72 but is smaller than a diameter D of the large diameter portion 71.

A width W2 of the basis portion of the two thickened portions 56 and 66 (two welding portions 56 and 66) is larger than the diameter D of the large diameter portion 71. A height H1 of the two thickened portions 56 and 66 (two welding portions 56 and 66) is longer than a length of the small diameter portion 72.

When a lower end of the large diameter portion 71 is positioned at the position 73a of the two thickened portions 56 and 66 (two welding portions 56 and 66), a tip end of the small diameter portion 72 reaches the member 55 or is positioned in the vicinity of the member 55.

Fig. 2 shows a state in which the friction stir welding has been completed. Fig. 2 shows the joining (welding) region W at an upper side of Fig. 1. The joining region at a lower side is symmetrical with the upper side joining region. At a side of an outer face of the joining region W, the dent K is caused, directed toward an inner side of the hollow frame member. At both sides of the dent K there are thick parts 56T and 66T.

The thick parts 56T and 66T are remainders of the thickened parts 56 and 66. The thick parts 56T and 66T include matters which are plastically deformed. A bottom face of the dent K is positioned at the outer side portion 73a, outward from an outer face of the plates 51 and 61.

In a case where the upper side face of Fig. 1 is the outer face side of the car body of a railway car, an excessive part of the upper face joining region (a part extending outward from the faces of the general portions (non-thickened portions) of the plates 51 and 61)) is machined by, illustratively, a grinding machine, and it is performed to have the same plan face as the upper faces of the general portion of the plates 51 and 61. Since the upper face side is machined, it is possible to carry out easily the cutting working.

At the lower face side, similarly to the above, the dent K and the thick parts 56T and 66T exist; however, when they exist at the inner face side of the car body, because they are covered by make-up plates it is unnecessary to machine them.

Fig. 3 shows a state in which the frame members 50 and 60 mounted on a bed stand 111 are joined through the upper side and the lower side, and next under a state in which they are mounted on the bed stand 111, the upper face side thick parts 56T and 66T have been machined.

According to the above structure, an occurrence of

the dent K extending to a level below the level of the faces of the general portions (non-thickened portions) of the plates 51 and 61 can be prevented substantially. As a result, it is not necessary to carry out padding welding and mending using the putty member.

Further, in the above-stated embodiment, the end portions 56a and 66a of the thickened parts 56 and 66 contact each other; however, in a case where a gap exists between the thickened parts, the base metal of the thickened parts 56 and 66 which has been fluidized under the friction stir welding is pushed into the gap. As a result, in a case of an existence of the gap, a defect is not generated in the joining region.

Concretely, when the height of the thickened part (H1 in Fig. 4) is 1 mm, two members having a gap of 1 mm therebetween can be joined without defect. Further, it is possible to position the dent K outside of an extension line of the outer face of the plates 51, 52 and 61, 62. Namely, the occurrence of the dent extending beyond the faces of the plates 51, 52 and 61, 62 can be prevented substantially and easily.

As seen in the foregoing, according to the present invention the two members to be joined can be in contact with each other, but need not be in contact; there can be a gap between the ends of the two members to be joined. Throughout the present disclosure, where it is described that the two members to be joined are adjacent (abutting) each other, the two members can be in contact or can have small gaps therebetween.

Illustratively, the width W2 of the basis portions of the thickened parts 56 and 66 is larger than a diameter D of the large diameter portion 71. The width W1 of the apex of the thickened parts 56 and 66 is larger than a diameter d of the small diameter portion 72. When the center of the rotary body 70 is shifted from the center of the thickened parts 56 and 66, the above-stated dimensions are determined under a consideration of the gap of the two frame members.

Further, the thickened parts 56 and 66 of the joining region, when joined, can have a trapezoid shape; in comparison with a case where the thickened parts 56 and 66 are extruded with four-sided shapes, in the present invention no excessive part exists. As a result, the present invention can dispense with a small amount of the hollow frame member, and further it is possible to lessen the manufacturing cost.

Further, it is possible to lessen the machining amount by the grinding machine, since, e.g., only remaining portions of the thickened parts need be machined. Further, as shown in Fig. 6, after sides 51a and 61a of the thickened parts 56 and 66 are stood up a little from the outer faces of the non-thickened portions of the plates 51 and 61, it is possible to provide the trapezoid shapes to the thickened portions 56 and 66.

The plate 54 prevents the plates 51 and 61 from bending at the thickened parts 56 and 66, toward the inner side, due to the compressive force caused by the rotary bodies 70 and 70.

In Fig. 1, the right-end shape structure of the hollow frame member 50 may employ the left-end shape structure of the hollow frame member and also may employ the right-end shape structure of the hollow frame member 60. The shape structure of the hollow frame member 60 can employ similar structure. In a word, it is preferable to joint the two hollow frame members.

The rotary body 70 is moved by detecting the abutting portion using an optical sensor. By detecting the slope faces 56c and 66c of the thickened parts 56 and 66, the position in the width direction of the rotary body 70 is determined. As shown in Fig. 7, the slope faces 56n and 66nm for sensing can be provided at a part to which the thickened parts 56m and 66m are opposite. The slope face 56n (66n) can be provided respectively to both of the thickened parts 56m and 66m or can be provided to one of the thickened parts 56m and 66m.

In each of the above-stated embodiments, the two end faces 56a and 66a of the two joining regions are parallel to the axis center of the rotary body 70; however, the two end faces 56a and 66a can be inclined against the axis center of the rotary body 70. For example, the end face 56a of one member 50 is inclined and against to this end face 56a the end face 66a of another member 60 can be overlapped at the upper side.

According to this structure, even when the gap between the two end faces is large, according to the rotation of the rotary body 70 it is possible to prevent the outflow of the fluidized metal from the extruded member 55. This structure is suitable to the connection of mutual pipes.

A joining apparatus will be explained referring to Fig. 8A. The hollow frame members 50 and 60 are mounted on the bed stands 111, 111 and fixed by a cramp 113. The abutting portions of the two hollow frame members 50 and 60 are temporarily welded suitably.

An upper side rotary body 70 is hung down from a running body 121 which is run toward a width direction. The running body 121 is moved along an upper portion frame of a gate type running body 122. The running body 122 is run along a rail 123 which is arranged to both sides, along a longitudinal direction, of the hollow frame members 50 and 60.

A lower side rotary body 70 is provided on a running body 131 which is arranged between two seats 111 and 111. The running body 131 is mounted on the running body 132 and is moved toward the width direction.

The running body 132 is run along the rail 133 and also along the longitudinal direction of the hollow frame members 50 and 60. The lower side rotary body 70 is provided on a lower portion of the upper side rotary body 70. The running bodies 121 and 131 also move the rotary bodies 70 and 70 in the vertical direction.

Plural rollers 124 and 134 for pressing the hollow frame members 50 and 60 are provided on the running bodies 121 and 131. The rollers 124 and 134 are arranged at a front portion of the rotary bodies 70 and 70

and on both sides of the thickened parts 56 and 66. The rollers 124 and 134 are provided with plural rows along the running direction as occasion demands. Rollers can be added in front of and to the rear of the rotary body 70.

The running bodies 121 and 131 have a sensor (not shown in the figure) which can detect the position to be joined. The running bodies 121 and 131 are moved in the width direction by the sensor. In a case a laser is used as the sensor, the slope faces 56c, 56c and 66c, 66c are found and a center to be joined is detected.

After the joining of the upper face and the lower face of the hollow frame members 50 and 60 using the rotary bodies 70 and 70, and under a state in which the hollow frame members 50 and 60 are mounted on the bed stands 111 and 111, the hollow frame members 50 and 60 are finished smoothly by machining off the thick parts of the upper face.

When the machining grinding working is carried out by a manual working, it can be finished more smoothly. For this reason, it is possible to put on at the upper face the thick part for carrying out the machining working.

Further, first of all, since the thick part is machined leaving a little using the machine, and after that the remaining thick part is machined by manual working, it is possible to shorten the cutting working. In this case the rotary body 70 leaves a rear portion of running body 121 unoccupied, and the cutting tool is provided on the running body 121. And in a case where the rotary body 70 is rotated, the cutting tool carries out the cutting working.

For example, as shown in Figs. 8B and 8C, to the rear of the rotary body 70 of the upper face side, an end milling machine 126 is provided on the upper face side running body 121. The end milling machine 126 cuts off the thick parts 56T and 66T. A lower end of the end milling machine 126 is positioned at an upper portion a little from the upper faces of the upper face plates 51 and 61 of the hollow frame members 50 and 60. A diameter of the end milling machine 126 is sufficiently larger than the widths of the thick parts 56T and 66T which are positioned at the above-stated position. The rollers 124 and 134 push down a vicinity of the end milling machine 126 from an upper portion and a lower portion and therefore a cutting amount by the end milling machine 126 is made uniformly.

In the above-stated embodiments, a pair of the hollow frame members have respectively the thickened parts at the end portions; however, as shown in Fig. 8D, it is possible to constitute a case where only one of the hollow frame members has a thickened part. A metal of the thickened part 66 is moved at a clearance between the hollow frame members 50 and 60 and an upper face of the plate of the hollow frame member 50. Further, similarly to the above, in one hollow frame member 60 the thickened part is formed at the upper face plate 61, and in another hollow frame member 50 the lower face 52 has the thickened part.

In the above-stated embodiments, the frame member (e.g., an extruded frame member) is exemplified as

a hollow frame member; however, it is possible to apply the present invention to a non-hollow, e.g., extruded, frame member. Hereinafter, such embodiments will be explained.

Fig. 9 shows an example of a joint structure which has the thickened parts 34 and 35 at the end portions of the plate-shape extruded frame members 31 and 32, and the frame members 31 and 32 are joined by abutting the thick parts 34 and 35 to each other and friction stir welding. During the welding, the extruded frame members 31 and 32 are arranged on backing tools (bed stands) 36. To prevent the backing tools from joining with the joining region W, those backing tools 36 are made of materials harder than the materials of the extruded frame members 31 and 32.

Along to the abutting face of this joint, since the rotary body 70 is rotated and moved, then the joining region W shown in Fig. 10 can be obtained. The conditions for the rotary body 70 against the thickened parts 34 and 35 are similar to those of the above-stated embodiments.

Next, as shown in Fig. 11, the dent K and the thick parts are removed smoothly using the grinding machine, etc. The roller 124, etc., of the joining apparatus is similar to those of the above-stated embodiments.

Further, in a case where the extruded frame member, etc., has only one joining region, in the embodiment shown in Fig. 8A, in place of the lower side rotary body 70, a roll for supporting the extruded frame member can be arranged. With this structure, it is unnecessary to support a whole face of the frame members 31 and 32; as a result the bed stand structure can be simplified.

An embodiment shown from Fig. 12 to Fig. 14 shows a case where one face of each of the frame members 37 and 38 has plural ribs 39; and at an opposed face to the face having the ribs 39 the extruded frame members 37 and 38, having the thickened parts 34b and 35b, are joined by friction stir welding. The bed stand 36B mounts the lower ends of the ribs 39 and the lower faces of the thickened parts 34 and 35. The friction stir welding is performed similarly to the above-stated embodiments.

An embodiment shown from Fig. 15 to Fig. 16 shows a case where the extruded frame members 37c and 38c, having the thickened parts 34b and 35b, are provided at a side of the ribs 39. With this structure, a side of a bed stand 36C becomes flat.

As a result, in a case where at the opposite side of the ribs 39 a little unevenness is permitted, it is possible to delete the finishing process for making the joining smooth, so that the joined structure can be manufactured at a low cost. The joining region W is a good joining region and a predetermined thickness thereof can be obtained.

One embodiment shown from Fig. 17 to Fig. 19 will be explained. In Fig. 17, a side structure body 416 of a railway vehicle is comprised of plural extruded frame members 150 and 160. Each of the extruded frame

members 150 and 160 between an entrance and exit port 171 and a window 172, and between the window 172 and the window 172, extend in a longitudinal direction in Fig. 17 (that is, have their length extending in this longitudinal direction). Each of the extruded frame members 160 and 160 at the lower portions of the window 172 and at the upper portions of the window 172 extend in a lateral direction in Fig. 17 (that is, have their length extending in this lateral direction). Namely, the extruded frame members 150 and the extruded frame members 160 extend in directions (that is, have their lengths) orthogonal to each other.

The extruded frame members 150 and 150, which extend in (have their lengths extending in) the same direction, are joined to each other, and the extruded frame members 160 and 160, which extend in (have their lengths extending in) the same direction, are joined to each other, by providing the thickened parts, similarly to the above-stated embodiments.

An intersecting portion of the directions that the frame members 150 and 160 extend is shown in Fig. 18. Fig. 18 shows a condition before the friction stir welding. The extruded frame members 150 and 160 have a rib 153 and a rib 163 at one side of the plates. The extruded frame members 150 and 160 are not the hollow frame members. The extruded frame members 150 and 160 mount the plate 151 and the plate 161 on a bed stand 36C. The ribs 153 and 163 direct toward the upper portions. The sides of the ribs 153 and 163 are the inner side of the car, and the sides of the plates 151 and 161 are the outer side of the car.

The end portion of the extruded frame member 150 is extruded to a side of the rib 153 and constitutes a thickened part 156. The thickened part 156 is extruded further toward the extruded frame member 160 to be welded and constitutes an extruded part 157. The extruded part 157 is overlapped with an inner side of the plate 161 of the extruded frame member 160 (the side of the rib 163). The rib 163 of the part of the extruded part 157 is cut off and removed. Illustratively, an extruded amount L2 of the extruded part 157 is the same as a width L1 of the thickened part 156. Namely, the extruded part 157 corresponds to the thickened part 156. A tip portion of the extruded part 157 has an oblique side surface similarly to that of the thickened part 156.

By inserting the rotary body 70 from an upper portion, when the friction stir welding is carried out, since the extruded part 157 exists overlying a clearance 150c between the end portions 150b and 160b of the two extruded frame members 150 and 160, the metal of the extruded part 157, etc., is supplied to the clearance 150c. Further, the metal is supplied also to the upper portion of the extruded frame member 160. As a result, in a case of the comparison with structure which did not have the thickened part 156 and the extruded part 157, and further in comparison with structure which did not have only the extruded part 157, in this case a good welding can be obtained.

Since by cutting off the rib 163 of the extruded frame member 160 and the extruded frame member 160 is overlapped by the extruded part 157, the plate 161 at the vicinity of the extruded part 157 can be pressed down, and a good welding can be obtained.

A triangular-shaped groove 158 is provided at an outer face of the thickened part 156 which is positioned between the end portion 150b of the extruded frame member 150 and the end portion 160b of the extruded frame member 160. This groove 158 works a role of a positional mark for determining initially the position of the rotary body 70. This groove 158 further works a role of a mark for the sensor.

Fig. 20 shows a case where the thickened part 156 and the extruded part 157 are not provided at the side of the rib 153. The ribs 153 and 163 are mounted on a bed stand 36B. The thickened part 156, the extruded part 157 and the plates 151 and 161 surrounding these parts are mounted on a bed stand which projects toward an upper portion from the stand 36B. The rib 163 at the vicinity of the end portion of the extruded frame member 160 is cut off. The thickened part 156 and the extruded part 157 of the extruded frame member 150 are positioned at the side of the plate 151 (the outer face side of the car).

In a case of the welding of the extruded frame members in which the extruded direction is orthogonal, it is possible to use structure having only the thickened part 156 and not the extruded part 157. Further, the provision of the extruded part toward the adjacent member can be adapted to the hollow extruded frame member, etc. Further, the provision of the extruded part can be adapted to joining two extruded frame members which are not orthogonal, namely, to the welding of two parallel members.

The above method can be adopted to mutual honeycomb panels. Each honeycomb panel comprises two face plates, a honeycomb core member arranged between the two face plates, and a flange member arranged at a surrounding portion of the core member, etc.

The object matter to be joined can be pipes, etc. In this case, the plate of the above-stated embodiments will be replaced with a cylinder suitably.

Through use of the present invention, dents extending below the surfaces of the joined members can be avoided. Therefore, finishing of the joined members, to provide a smooth surface extending across the joint between the joined members, can be simplified.

Furthermore, even when there is a gap (or gaps) between the members to be joined by the friction stir welding and these gaps are large, dents extending below the surfaces of the joined members can be avoided, simplifying finishing work in providing a smooth surface extending across the joint.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristic thereof. The present embodiments are therefore to be considered in all respects as illustrative and

not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

## Claims

1. A friction stir welding method, comprising the steps of:

positioning adjacent to each other two members to be welded together, a first end of one of the two members being positioned adjacent a first end of the other of the two members, said first end of at least one of the two members having a thickened part, thicker than a remaining part of said at least one of said two metal members, said thickened part protruding toward a tool for performing the friction stir welding; and performing friction stir welding with said tool, at said first ends of the two metal members, so as to weld the two members to each other.

2. The friction stir welding method according to claim 1, wherein after performing the friction stir welding, material of the members at the location of the thickened part is at a level higher than a surface of the remaining part of the member having the thickened part.
3. The friction stir welding method according to claim 1, wherein said tool is a rotary body which has two cylindrical portions, a first cylindrical portion, having a first diameter, and a second cylindrical portion, extending along a same axis as the first cylindrical portion, having a second diameter larger than the first diameter, such that the first cylindrical portion projects from the second cylindrical portion; and wherein the step of performing friction stir welding comprises (a) rotating the rotary body; (b) inserting the rotary body such that the first cylindrical portion is inserted into a first region including the first ends of the two members to be welded, and the second cylindrical portion is inserted into a second region including at least part of a thickness of the thickened part; and (c) moving relatively the rotating rotary body with the first and second cylindrical portions inserted as in (b), along the adjacent two members, such that the first ends of the two members are welded together so as to weld the two members.
4. The friction stir welding method according to claim 3, wherein said second region, into which the second cylindrical portion is inserted, does not extend below a level of an extension of a surface of said remaining part of said at least one of said two mem-



bers.

5. The friction stir welding method according to claim 3, wherein the adjacent two first ends of the two members are in contact with each other.
6. The friction stir welding method according to claim 3, wherein the adjacent two first ends of the two members are spaced from each other.
7. The friction stir welding method according to claim 6, wherein the adjacent two first ends of the two members are spaced up to 3mm from each other.
8. The friction stir welding method according to claim 1, wherein said thickened part has two sides, a first side at the first end of the member having said thickened part and a second side opposite the first side, and wherein the second side extends to a surface of the remaining part of the metal member having the thickened part, the second side making an angle of less than 90° with an extension of a surface of a remaining part of the member having the thickened part.
9. The friction stir welding method according to claim 8, wherein said angle is in a range of 15°-60°.
10. The friction stir welding method according to claim 1, wherein the two members are adapted to form an exposed part of a body, and wherein surfaces of the two members having had the thickened part protruding therefrom constitute exposed surfaces of the body.
11. The friction stir welding method according to claim 10, wherein after performing the friction stir welding, material at the location of the thickened part is at a level higher than a surface of the remaining part of the member having the thickened part, and wherein the method includes a further step, after performing the stir friction welding, of machining material at the location of the thickened part such that a surface at the location of the thickened part is at substantially a same level as the surface of the remaining part of the metal member having the thickened part.
12. The friction stir welding method according to claim 1, wherein after performing the friction stir welding, material at the location of the thickened part is at a level higher than a surface of a remaining part of the metal member having the thickened part, and wherein the method includes a further step, after performing the stir friction welding, of machining material at the location of the thickened part such that a surface at the location of the thickened part is at substantially a same level as the surface of the remaining part of the member having the thickened

part.

13. The friction stir welding method according to claim 1, wherein, in a product using the two members welded together, surfaces of the two members having had the thickened parts protruding therefrom are concealed surfaces in the product.
14. The friction stir welding method according to claim 1, wherein each of the two members has said thickened part.
15. The friction stir welding method according to claim 14, wherein said tool is a rotary body which has two cylindrical portions, a first cylindrical portion, having a first diameter, and a second cylindrical portion, extending along a same axis as the first cylindrical portion, having a second diameter larger than the first diameter, such that the first cylindrical portion projects from the second cylindrical portion; and wherein the step of performing friction stir welding comprises (a) rotating the rotary body; (b) inserting the rotary body such that the first cylindrical portion is inserted into a first region including the first ends of the two members to be welded, and the second cylindrical portion is inserted into a second region including at least part of a thickness of the thickened part; and (c) moving relatively the rotating rotary body with the first and second cylindrical portions positioned as in (b), along the adjacent two members, such that the first ends of the two members are welded together so as to weld the two members.
16. The friction stir welding method according to claim 14, wherein said second region, into which the second cylindrical portion is inserted, does not extend below a level of an extension of a surface of remaining parts of each of the two members other than the thickened parts.
17. The friction stir welding method according to claim 14, wherein thickened parts of the two members are placed adjacent each other.
18. The friction stir welding method according to claim 17, wherein the thickened parts of the two members protrude to a same height over the surface of the remaining parts of the two members, and in positioning the two members adjacent each other the thickened parts of the two members are located at a same level, whereby the remaining parts of each of the two members are at a same level.
19. The friction stir welding method according to claim 17, wherein each thickened part has two sides, a first side at the first end of the member having said thickened part and a second side opposite the first side, and wherein the second side is sloped to a

surface of the remaining part of the member having the respective thickness part.

20. Product formed by the method of claim 18.

21. Product formed by the method of claim 14.

22. Product formed by the method of claim 13.

23. Product formed by the method of claim 12.

24. Product formed by the method of claim 11.

25. Product formed by the method of claim 1.

26. A friction stir welding method, comprising the steps of:

positioning two members adjacent to each other, each of the two members being comprised of two parallel plates and plates connecting the two parallel plates, each of the two parallel plates of at least one of the two members having a thickened part at an end thereof, the thickened part extending in a direction away from the other of the two parallel plates of this member, the thickened part of each of the two parallel plates of one of the two members being positioned adjacent a thickened part of the parallel plates of the other of the two members, whereby thickened parts of one of the two members are located adjacent thickened parts of the other of the two metal members at both surfaces of the members;  
performing friction stir welding at substantially a same time at both surfaces of the members; after performing the friction stir welding, whereby a remaining portion of the thickened parts remains, machining said remaining portion on one of the surfaces of the members.

27. The friction stir welding method according to claim 26, wherein when performing the friction stir welding the two members are positioned horizontally, with the surfaces of the members respectively being upper and lower surfaces of the horizontally positioned members, and wherein in said machining only the remaining portion on the upper surface is machined.

28. The friction stir welding method according to claim 26, wherein the plates connecting the two parallel plates of one of the two members include a plate adjacent an end of said one of the two members, extending between corresponding ends of the two parallel plates of said one of the two members, at the thickened parts.

29. Product formed by the method of claim 28.

30. Product formed by the method of claim 26.

31. A friction stir welding method, comprising the steps of:

positioning adjacent to each other two members to be welded together, a first end of one of the two members being positioned adjacent a first end of the other of the two members, the first end of at least one of the two members having a thickened part, thicker than a remaining part of the at least one of the two members, said thickened part protruding from a side of the at least one of the two metal members;  
performing friction stir welding at said first ends of the two members, so as to weld the two metal members together, by applying a rotary body to the thickened part; and  
machining the side of the at least one of the two members that had the thickened part protruding therefrom, said machining being carried out by a cutting tool that moves together with a rotary body used for performing the friction stir welding.

32. The friction stir welding method according to claim 31, wherein when performing the friction stir welding the two members are positioned horizontally, and the side from which the thickened part protrudes faces upward.

33. A friction stir welding method, comprising:

positioning first and second members adjacent to each other such that an extruded part of the first member, constituting an end portion of the first member, overlaps an end portion of a first surface of the second member, such that the extruded part extends to a higher level than the first surface of the second member, so as to protrude toward a tool for performing the friction stir welding; and  
performing the friction stir welding with said tool, at the end portions of the first and second members, so as to weld the first and second members to each other.

34. The friction stir welding method according to claim 33, wherein the first member further comprises a thickened part adjacent the extruded part, in a direction away from an edge of the first member, the thickened part protruding from a remaining surface of the first member, other than the thickened part and the extruded part; and wherein the friction stir welding is performed at the thickened part and at the end portions of the first and second members.

35. The friction stir welding method according to claim 34, wherein the thickened part is positioned adjacent the end portion of the second metal member, and protrudes to a same level as the extruded part.

36. The friction stir welding method according to claim 34, wherein said tool is a rotary body which has two cylindrical portions, a first cylindrical portion, having a first diameter, and a second cylindrical portion, extending along a same axis as the first cylindrical portion, having a second diameter larger than the first diameter, such that the first cylindrical portion projects from the second cylindrical portion; and wherein the step of performing friction stir welding comprises (a) rotating the rotary body; (b) inserting the rotary body such that the first cylindrical portion is inserted into a first region including the end portion of the second member and a part of the first member adjacent thereto, and the second cylindrical portion is inserted into a second region including at least part of a thickness of the extruded part but not more than a full thickness thereof; and (c) moving relatively the rotating rotary body with the first and second cylindrical portions inserted as in (b), along the adjacent first and second members, so as to weld the first and second members together.

37. The friction stir welding method according to claim 33, wherein said tool is a rotary body which has two cylindrical portions, a first cylindrical portion, having a first diameter, and a second cylindrical portion, extending along a same axis as the first cylindrical portion, having a second diameter larger than the first diameter, such that the first cylindrical portion projects from the second cylindrical portion; and wherein the step of performing friction stir welding comprises (a) rotating the rotary body; (b) inserting the rotary body such that the first cylindrical portion is inserted into a first region including the end portion of the second member and a part of the first member adjacent thereto, and the second cylindrical portion is inserted into a second region including at least part of a thickness of the extruded part but not more than a full thickness thereof; and (c) moving relatively the rotating rotary body with the first and second cylindrical portions inserted as in (b), along the adjacent first and second members, so as to weld the first and second members together.

38. A friction stir welding method, comprising:

positioning a first member adjacent a second member, the first member having a length direction orthogonal to a length direction of the second member, an extruded part, constituting an end portion of the first member, overlapping an end portion of a first surface of the second member such that the extruded part of the first

member extends to a higher level than the first surface of the second member, so as to protrude toward a tool for performing the friction stir welding; and

performing the friction stir welding with said tool, at the end portions of the first and second members, so as to weld the first and second metal members to each other.

39. The friction stir welding method according to claim 38, wherein said tool is a rotary body which has two cylindrical portions, a first cylindrical portion, having a first diameter, and a second cylindrical portion, extending along a same axis as the first cylindrical portion, having a second diameter larger than the first diameter, such that the first cylindrical portion projects from the second cylindrical portion; and wherein the step of performing friction stir welding comprises (a) rotating the rotary body; (b) inserting the rotary body such that the first cylindrical portion is inserted into a first region including the end portion of the second member and a part of the first member adjacent thereto, and the second cylindrical portion is inserted into a second region including at least part of a thickness of the extruded part but not more than a full thickness thereof; and (c) moving relatively the rotating rotary body with the first and second cylindrical portions inserted as in (b), along the adjacent first and second members, so as to weld the first and second members together.

40. A friction stir welding method, comprising:

positioning a first member adjacent a second member, the first member having a length direction orthogonal to a length direction of the second member, the first member having two sides extending in the length direction thereof and ends extending orthogonally to said sides, the second member having sides extending in the length direction thereof and ends extending orthogonally to the sides of the second member, one side of the first metal member having an extruded part, positioned to overlap a region of the second member extending from one of the ends thereof, such that the extruded part extends to a higher level than a surface of the second member so as to protrude toward a tool for performing the friction stir welding, the other side of the first metal member having a first thickened part protruding toward said tool; and performing the friction stir welding with said tool, at the extruded part of the first member and said region of the second metal member overlapped thereby, and at a part of the first metal member adjacent said region of the second member, so as to weld the first and second members to each other.

41. The friction stir welding method according to claim 40, wherein the part of the first member adjacent said region of the second member is a second thickened part, protruding from the first member to a same level as the extruded part.

42. The friction stir welding method according to claim 40, wherein said tool is a rotary body which has two cylindrical portions, a first cylindrical portion, having a first diameter, and a second cylindrical portion, extending along a same axis as the first cylindrical portion, having a second diameter larger than the first diameter, such that the first cylindrical portion projects from the second cylindrical portion; and wherein the step of performing friction stir welding comprises (a) rotating the rotary body; (b) inserting the rotary body such that the first cylindrical portion is inserted into a first region including the end portion of a second member and a part of the first member adjacent thereto, and the second cylindrical portion is inserted into a second region including at least part of a thickness of the extruded part but not more than a full thickness thereof; and (c) moving relatively the rotating rotary body with the first and second cylindrical portions inserted as in (b), along the adjacent first and second members, so as to weld the first and second members together.

43. A joined structure, comprising:

two members each comprised of two parallel plates and plates for connecting the two parallel plates, the parallel plates respectively forming first and second sides of the joined structure, end portions of the two members having been joined in a joining region, said joining region being provided at both the first and second sides of the joined structure, whereby one of the two parallel plates of one of the two members is joined to one of the two parallel plates of the other of the two members at ends thereof, and the other of the two parallel plates of one of the two members is joined to the other of the parallel plates of the other of the two members at ends thereof,

wherein an outer surface of the joining region at the first side of the joined structure is flat, and wherein an outer surface of the joining region at the second side of the joined structure has a thick part, which protrudes from a remaining part of the second side of the joined structure.

44. The joined structure according to claim 43, wherein the end portions of the two members have been joined by friction stir welding.

45. The joined structure according to claim 43, wherein the thick part of the joining region of the second side

has a dent portion, extending into the thick part.

46. The joined structure according to claim 45, wherein said dent portion extends to a level that still protrudes from the remaining part of the second side of the joined structure.

47. The joined structure according to claim 43, wherein the thick part of the joining region of the second side has a dent portion and raised portions at sides of the dent portion.

48. The joined structure according to claim 47, wherein said dent portion extends to a level that still protrudes from the remaining part of the second side of the joined structure.

49. The joined structure according to claim 48, wherein the end portions of the two members have been joined by friction stir welding.

50. The joined structure according to claim 47, wherein said raised portions at the sides of the dent portion each protrude a substantially same distance from the remaining part of the second side of the joined structure.

51. The joined structure according to claim 43, said joined structure forming part of a vehicle body, the first side of the joined structure forming an outer side of the vehicle body.

52. The joined structure according to claim 51, wherein said vehicle body is a railroad car.

53. A joined structure, comprising:

two members, each comprised of two parallel plates and a plurality of further plates for connecting the two parallel plates, the parallel plates respectively forming first and second sides of the joined structure;

an end portion of each of the two parallel plates of one of the two members being friction stir welded respectively to an end portion of each of the two parallel plates of the other of the two members, forming respective friction stir welded portions at the first and second sides of the joined structure,

wherein, at one of the friction stir welded portions, at one of the first and second sides, there is a thick part protruding from the parallel plates, in a direction extending away from the further plates.

54. A joined structure, comprising:

two members, each of the two members having

a plate and a plurality of ribs extending away from one side of the plate, end portions of the plates of the two members being friction stir welded to each other at a friction stir welded portion, wherein said friction stir welded portion has a thick part protruding from the plates in a direction extending away from the ribs.

55. A joined structure, comprising:

first and second frame members, each comprised of two parallel plates and a further plate connecting between the two parallel plates, each of the frame members extending in a length direction, the length direction of the first frame member being orthogonal to the length direction of the second frame member, the two parallel plates of the first frame member having sides extending in the length direction of the first frame member and ends extending orthogonally thereto, the two parallel plates of the second frame member having sides extending in the length direction of the second frame member and ends extending orthogonally thereto; and

end portions of the two parallel plates of the first frame member, extending from an end thereof, being welded to side portions of the two parallel plates of the second frame member, extending from a side thereof, at weld portions;

wherein, in a weld portion between parallel plates, of the parallel plates of the first and second frame members, at one surface of the joined structure, the surface is flat with respect to surfaces of the respective parallel plates; and

wherein, in a weld portion between parallel plates, of the parallel plates of the first and second frame members, at another surface of the joined structure, the weld portion protrudes from surfaces of the respective parallel plates, in a direction away from the further plate.

56. A joined structure according to claim 55, wherein said joined structure is part of a vehicle; and wherein the first frame member forms a structural part between an entrance and exit part of the vehicle and a window opening thereof, and the second frame member forms the window opening.

57. A joined structure according to claim 56, wherein said vehicle is a railway vehicle.

58. A joined structure according to claim 55, wherein said joined structure is part of a vehicle, and wherein the first frame member forms a structural part between two windows, and the second frame member

forms an opening for one of the two windows.

59. A frame member, to be joined to another frame member to form a joined structure, comprising:

a plate member, having first and second opposed surfaces; and  
a plurality of ribs extending from the first surface of the plate member, wherein the plate member has first and second end portions respectively at opposite ends of the plate member, at least one of the first and second end portions being a thickened portion that protrudes from the second surface of the plate member, away from the plurality of ribs.

60. The frame member according to claim 59, wherein both the first and second end portions are said thickened portions.

61. A frame member, to be joined to another frame member to form a joined structure, comprising:

a plate member, having first and second opposed surfaces; and  
a plurality of ribs extending from the first surface of the plate member, wherein the plate member has first and second end portions respectively at opposite ends of the plate member, at least one of the first and second end portions being a thickened portion that protrudes from the second surface of the plate member, away from the plurality of ribs, the thickened portion having opposite first and second sides respectively adjacent to an edge of the plate member and farthest from said edge, said second side being sloped in extending from an apex of the thickened portion toward a remainder of the second surface of the plate member, other than the thickened portion.

62. A frame member, to be joined to another frame member to form a joined structure, comprising:

a plate member, having first and second opposed surfaces; and  
a plurality of ribs extending from the first surface of the plate member, wherein the plate member has first and second end portions respectively at opposite ends of the plate member, at least one of the first and second end portions being a thickened portion that protrudes from the first surface of the plate member, in a direction that the plurality of ribs extend.

63. The frame member according to claim 62, wherein the thickened portion has opposed first and second

sides, respectively adjacent to an edge of the plate member and farthest from said edge, said second side being sloped in extending from an apex of the thickened portion toward the first surface of the plate member.

64. A frame member, to be joined to another frame member to form a joined structure, comprising:

a pair of parallel plates and a further plate connecting between the pair of parallel plates, wherein each of the pair of parallel plates has first and second end portions respectively at opposite ends, at least one of the first and second end portions of each of the pair of parallel plates having a thickened portion, the thickened portion protruding from the parallel plates in a direction away from the further plate, and wherein each thickened portion has opposed first and second sides, respectively adjacent to an edge of a parallel plate and farthest from said edge, said second side being sloped in extending from an apex of the thickened portion toward a remainder of the parallel plate.

65. A frame member, to be joined to another frame member to form a joined structure, comprising:

a plate, having a plurality of ribs extending from only one side of the plate, wherein said plate has a thickened portion which protrudes from the plate, in a direction away from the plurality of ribs, and an extruded part forming an edge portion of the plate, the thickened portion including, in a thickness direction, a first portion which corresponds to a thickness of a remainder of the plate adjacent the thickened portion, and a second portion having a thickness so as to protrude from the plate.

66. The frame member according to claim 65, wherein said extruded part is adapted to overlap an adjacent frame member, and extends from the second portion of the thickened portion and substantially not from the first portion of the thickened portion.

67. The frame member according to claim 65, wherein the thickened portion and the extruded part extend along a length of the plate.

68. The frame member according to claim 65, wherein the thickened portion has a thickened part side extending from an apex of the thickened part to a surface of the remainder of the plate adjacent the thickened portion, the thickened part side being sloped.

69. A frame member, to be joined to another frame

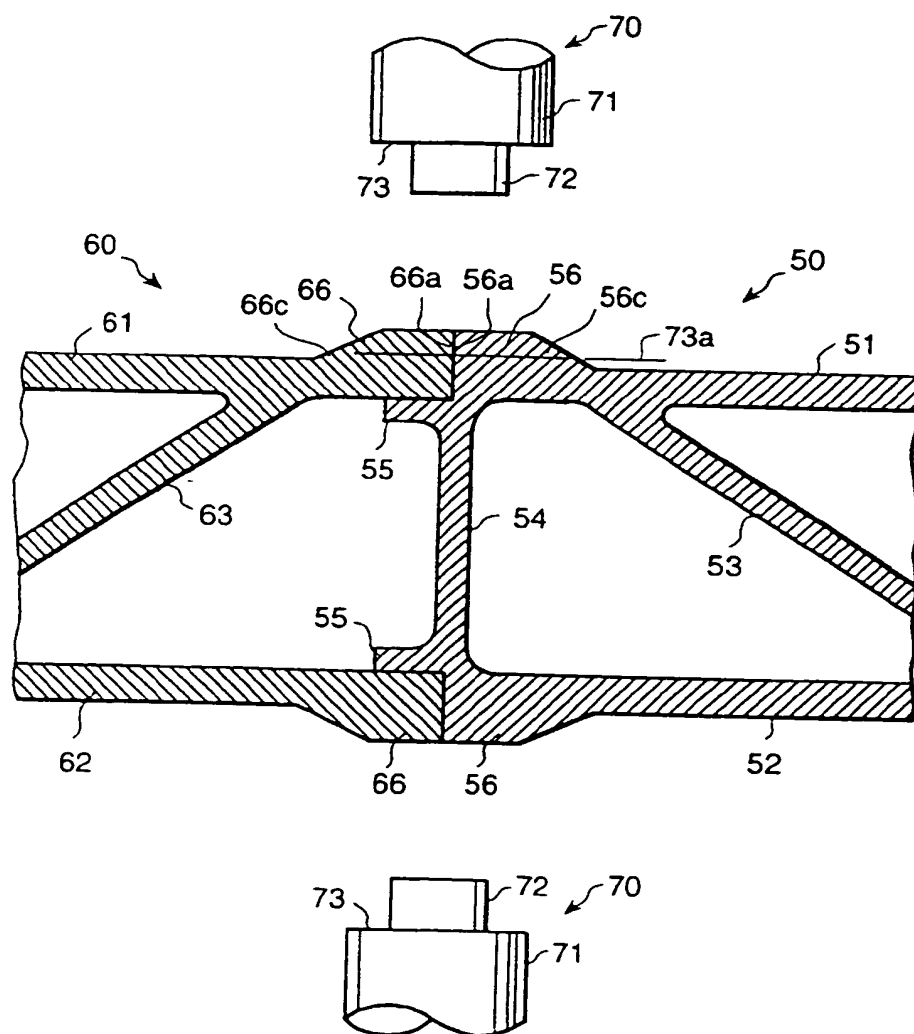
member to form a joined structure, comprising:

two plates, and at least one further plate connected between the two plates, wherein each of the two plates has a thickened portion which protrudes from a respective plate in a direction away from the at least one further plate, and an extruded part forming an edge portion of the respective plate, each thickened portion including, in a thickness direction, a first portion which corresponds to a thickness of a remainder of the respective plate adjacent the thickened portion, and a second portion having a thickness so as to protrude from the plate.

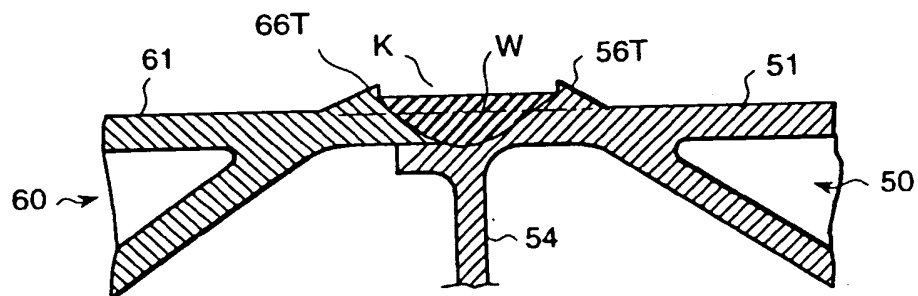
70. The frame member according to claim 69, wherein said extruded part is adapted to overlap an adjacent frame member, and extends from the second portion of the thickened portion and substantially not from the first portion of the thickened portion.

71. The frame member according to claim 69, wherein the thickened portion has a thickened part side extending from an apex of the thickened part to a surface of the remainder of the plate adjacent the thickened portion, the thickened part side being sloped.

FIG. 1



**FIG. 2**



**FIG. 3**

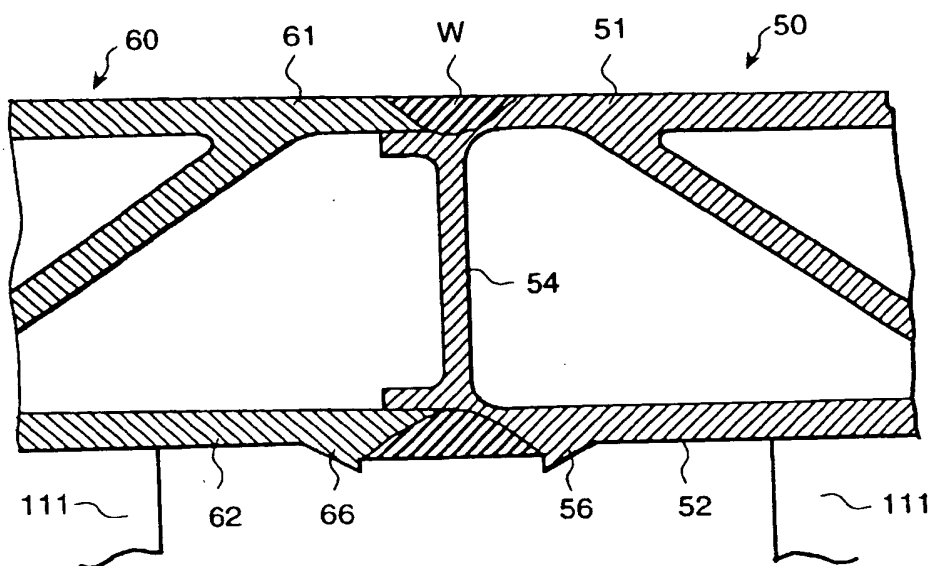




FIG. 4

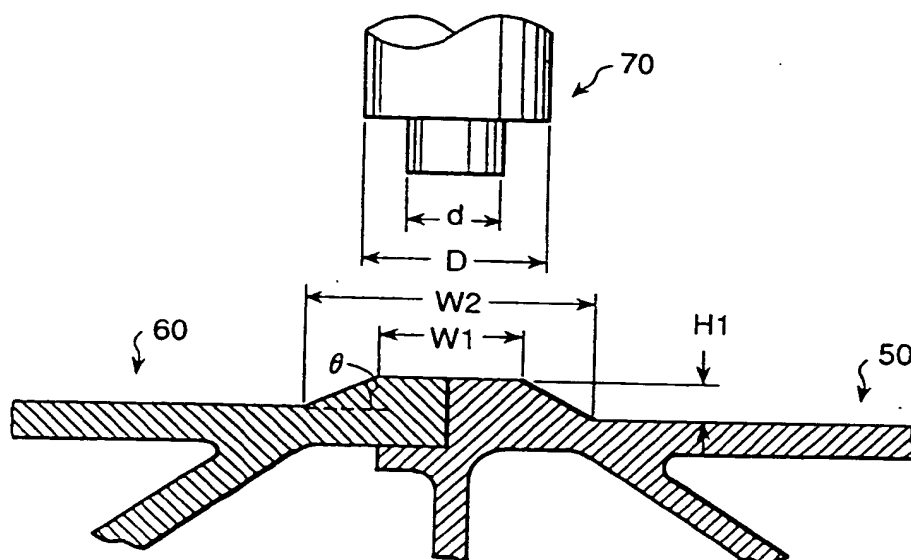


FIG. 5

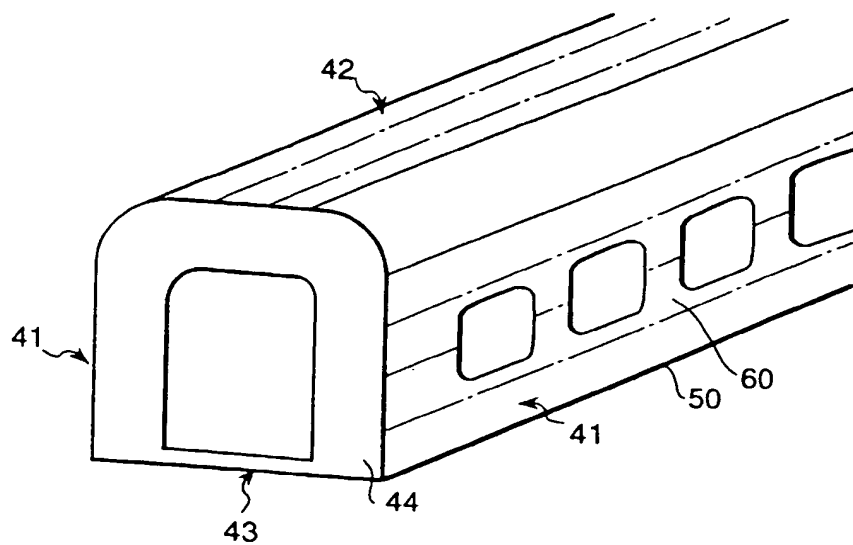


FIG. 6

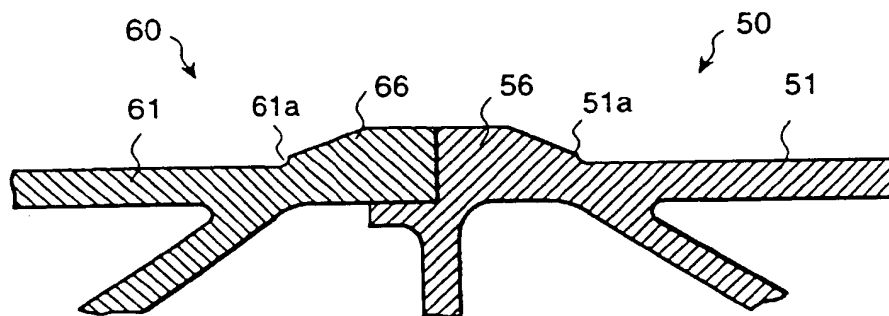


FIG. 7

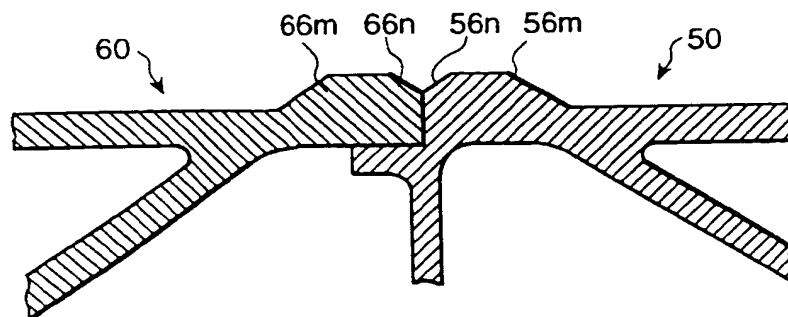


FIG. 8A

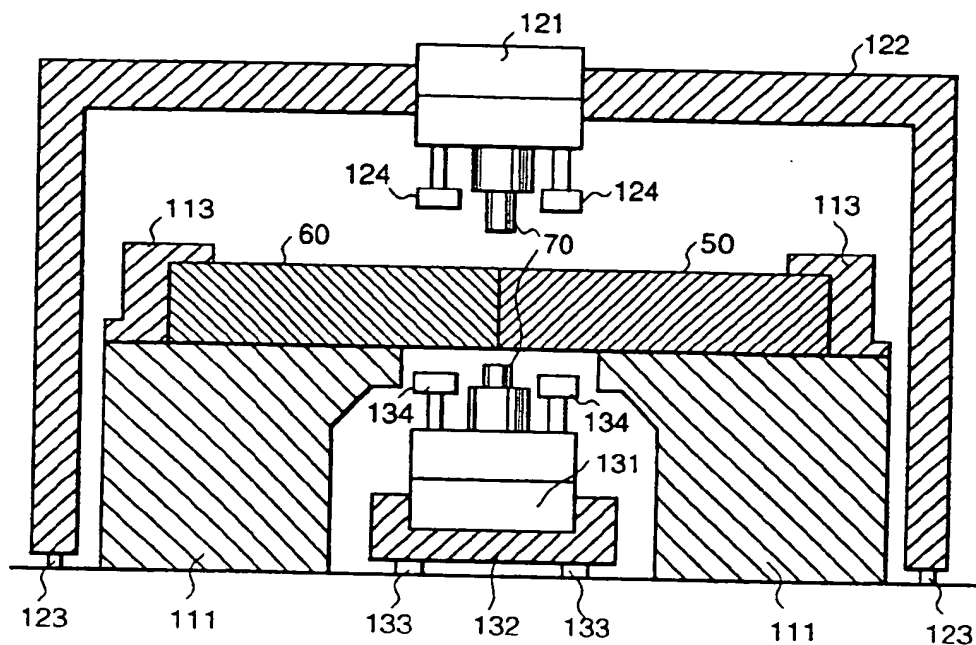


FIG. 8B

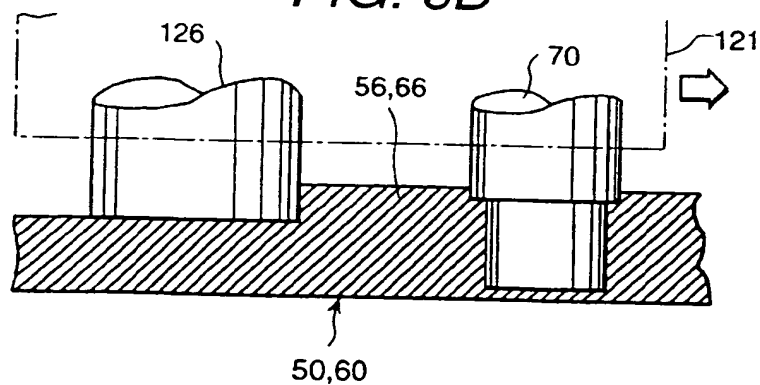
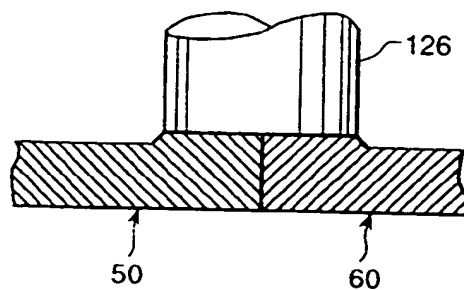
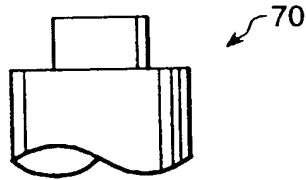


FIG. 8C





A cross-sectional view of a semiconductor device. It shows a substrate 36 with a thin layer 31 on top. The thin layer 31 has a central region 34 and side regions 35 and 32. The central region 34 is shown with a hatched pattern, while the side regions 35 and 32 are shown with a solid pattern. The substrate 36 is shown with a solid pattern.

FIG. 10

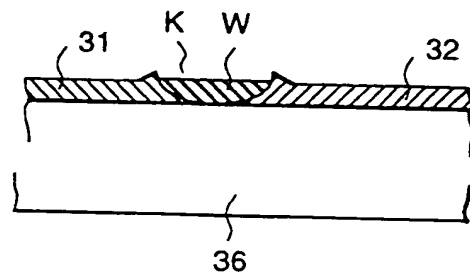


FIG. 11

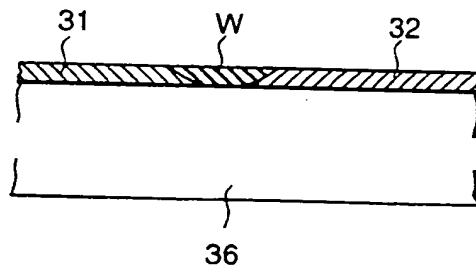


FIG. 12

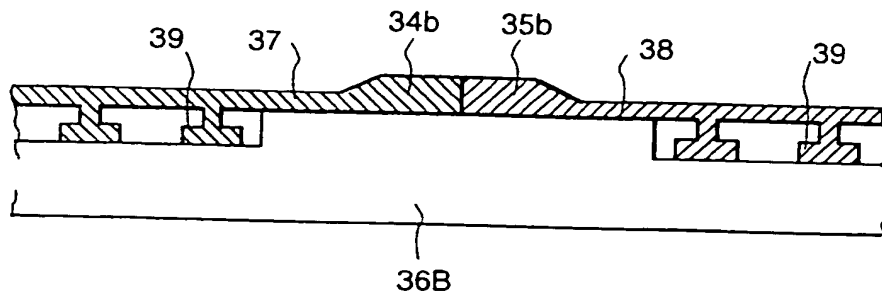


FIG. 13

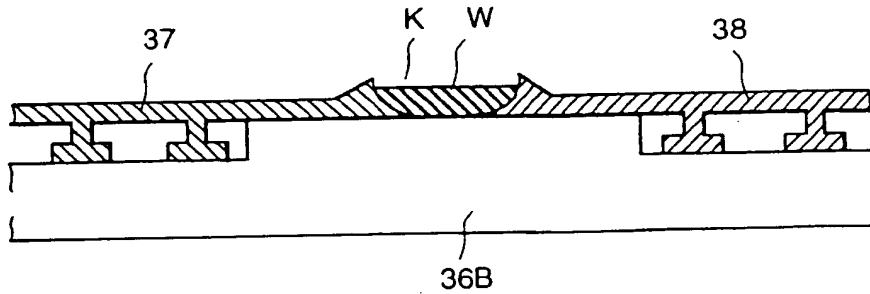


FIG. 14

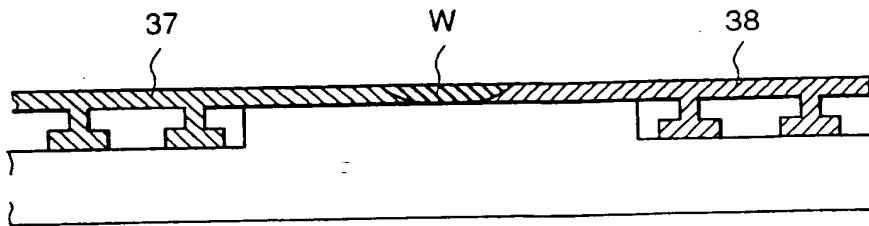


FIG. 15

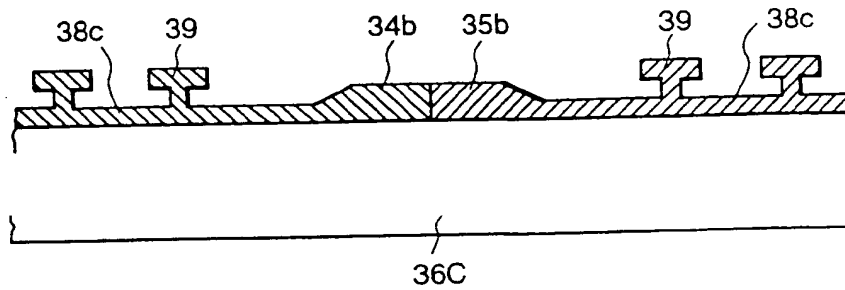


FIG. 16

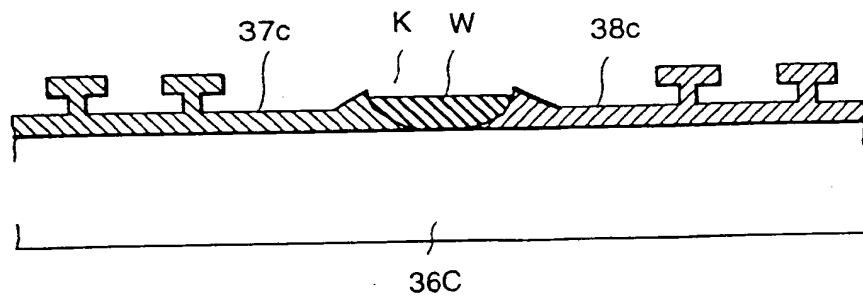


FIG. 17

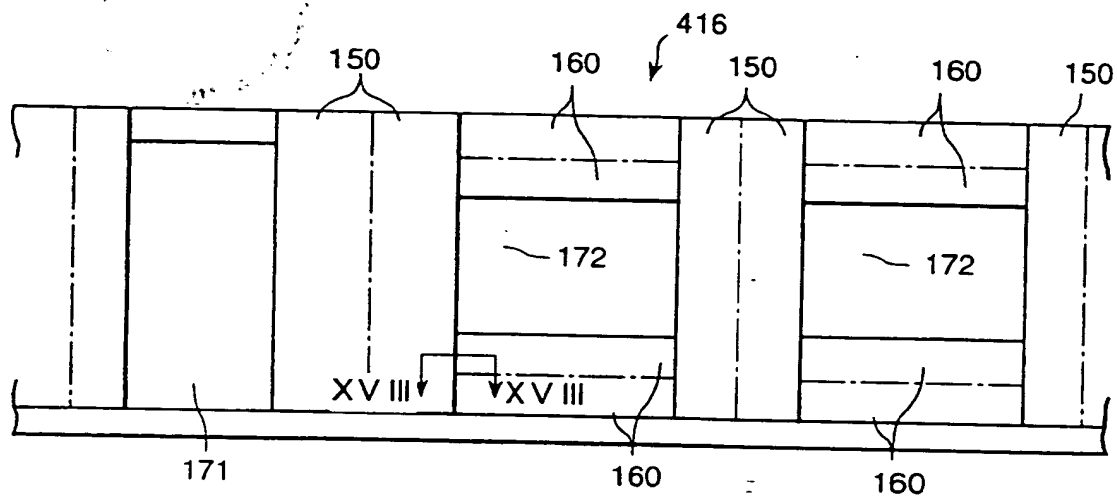


FIG. 18

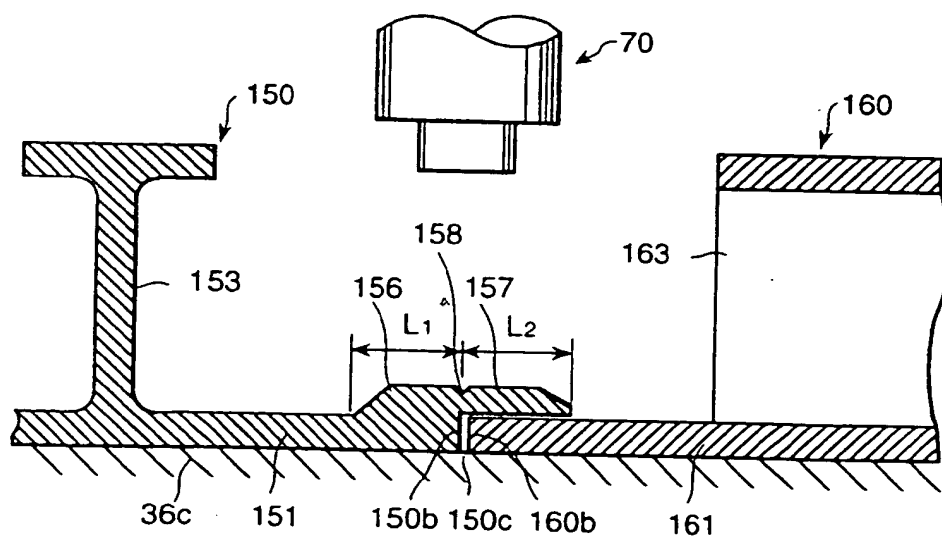




FIG. 19

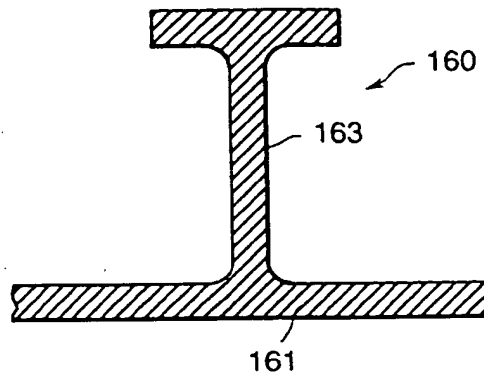


FIG. 20

